MODELLING OF DISCUS-FLIGHT

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The previous theoretical considerations about gyro stability of the discus are not in agreement with practical observations. Thus there exist a theoretical deficit about our understanding of discus flight and therefore our desire, to set up new tables of throw distances as a function of initial values and wind forces. A 3D-model of the discus flight is developed.

KEY WORDS: discus, modeling, flight

INTRODUCTION: Throw distance depends on the release parameters: height, velocity, angle of flight path and the angle between the surface of discus and direction of the wind (angle of attack). Discus flight trajectory is not a parabola since discus flight follows aerodynamic and those of gyroscopic motion laws. In most cases more than 10% of throw distances relate to aerodynamic effects.

According to TUTEVIC the angular momentum of the discus, given him at the moment of release, is big enough to keep the start angle over the whole flight, despite the aerodynamic forces (TUTEVIC, p. 49). But in practice the trajectory differs from the theoretical one (fig. 1), though the discus spins round by the required eight rotations per second. Not only, but usually due to by headwind the discus cants from horizontal into a nearly vertical position. The discus moves towards to an energetically stable status (minimal drag, minimal rotational energy).

Figure 1 - From right to left: approach and landing. The discus cants into a nearly vertical position.

METHODS: During the flight aerodynamic drag and lift affect the discus. Due to lift the discus often flies significantly further than the start parameters would suggest from current models (parabola distance). But during flight the aerodynamic forces likewise generate a torque, which acts on the discus. Because the discus has at release an angular momentum (when it leaves the hand) we must satisfy both equations: the flight of the centre of mass and the EULER´s gyro equations. The moment of aerodynamic forces cause the discus to move to a vertical position and lose lift. At the same time the discus drifts sideways. Thus we have not a planar problem like TUTEVIC, we must consider the spatio-temporal equations.

The complexion equations were solved numerically by a self written simulation program. All the coefficients of aerodynamic drag and lift as well as torque are measured in a wind tunnel (WINDKANAL WKK KLOTZSCHE). Actual competition discs don't possess a homogeneous density, the moments of inertia of the discus were investigated as usual with the aid of torsion scales (SOMMERFELD, S. 190).

For checking purposes the compression of incoming flow was calculated with the help of the simulation system for fluids FLOTRAN.

RESULTS AND DISCUSSION: During competitions we observed in the stadium that wind is perceived only from velocities of 2m/s. Wind velocity and hence effect on the discus increases with height. On the ground there is a turbulent layer which depends on the nature of structural surroundings of the competition area. The mean value W of wind strength depends on the height h as follows (exponential law):

$$W(h) = W_{ground} \cdot h^K$$

$$K \approx 0,25$$

The discus is balanced on its rotational axis. Therefore we have gyro equations of angular velocities about discus axes as follows. If M_1, M_2, M_3 are the components of moment of aerodynamic force about these axes respectively, then:

$$A \cdot \frac{d\omega_1}{dt} - (A - C)\,\omega_2\,\omega_3 = M_1$$

$$A \cdot \frac{d\omega_2}{dt} - (C - A)\,\omega_3\,\omega_1 = M_2$$

$$C \cdot \frac{d\omega_3}{dt} = M_3$$

The coefficients C and A are the moments of inertia about the symmetrical axis and orthogonal axes respectively. All three components of moment **M** of torque must be expressed as functions of the angle of incoming flow and the angles of spatial orientation of the discus. Finally the equations above only must be combined with those of flight of the centre of mass. That could be done, for instance, with the help of EULER´s angles. Excepting gravitation the required forces $\mathbf{F_W}$ (aerodynamic drag) and $\mathbf{F_A}$ (lift) are expressed as follows, if **w** describes the vector of incoming flow including wind:

$$\mathbf{w} = -\left(v_x + wind_x,\ v_y + wind_y,\ v_z + wind_z\right)$$

$$\beta = a\cos\left(\mathbf{n} \cdot \frac{\mathbf{w}}{w}\right) - \frac{\pi}{2} \qquad w = |\mathbf{w}|$$

$$\mathbf{F}_W = \frac{\rho}{2} F w^2 c_W(\beta) \cdot \frac{\mathbf{w}}{w} \qquad \mathbf{F}_A = \frac{\rho}{2} F w^2 c_A(\beta) \cdot \frac{\mathbf{w} \times (\mathbf{n} \times \mathbf{w})}{w^2}$$

Value ρ means the air density, F the abutting face of discus and **n** the orientation vector of its symmetric axis. Symbol β means the angle of incoming flow and as c_A and c_W we have the lift and drag coefficients of actual aerodynamic forces. The above described angle of incoming flow is the smallest angle between symmetric plane of discus and incoming flow. At first during the flight the angle of incoming flow increases and therefore the moment of forces. This results in the obtained sidewise rotation of the discus, influences the angle of incoming flow (it decreases), and further on lift and drag (both decrease), which causes the movement of centre of mass. To specify lift, drag and torque coefficients due to the rotational symmetry of the discus we have only to consider angles between 0 and about 60 degrees. From literature the values (TUTEVIC, 1969, p. 55) as shown in fig. 2 are known.

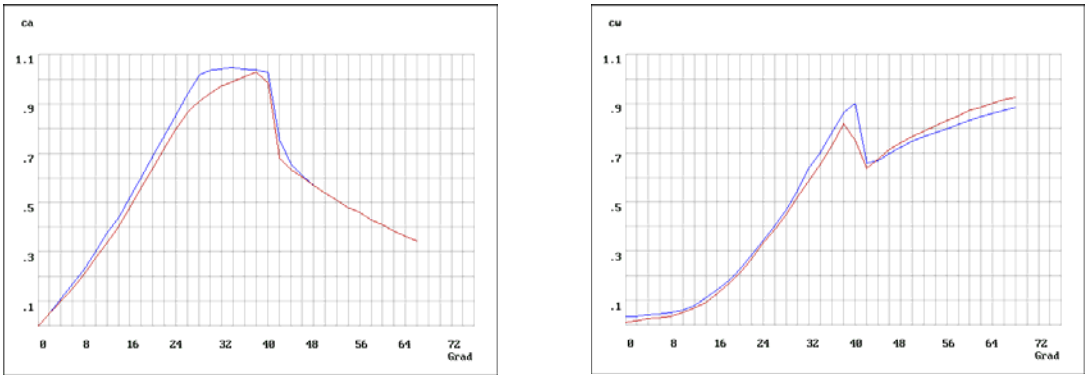

Figure 2 - Left: Lift coefficients subject to angle of incoming flow β (men's discus higher values, women's discus lower values). Right: Drag coefficients.

The best flight characteristics result from a high c_A/c_W ratio. The best parameters range between 5 and 15 degrees. We note an instability round about a critical angle of 40 degrees where the lift suddenly decreases. The discus begins to lose height. To understand the effect, we modelled the performance of pressure (simulation system FLOTRAN). In fact, the laminar layer on the discus changes here to a turbulent flow.

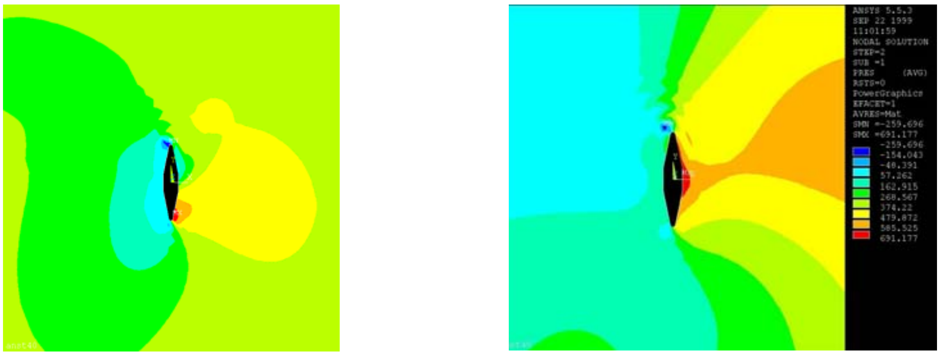

Figure 3 - Pressure performance on discus (computer simulation on system FLOTRAN for fluids). Angle of incoming flow 40 degrees from right lower corner. Left picture: left on the bottom of discus one can identify the pressure point and left above behind discus turbulence. The whole field left from discus shows turbulences. Right picture: only for comparison the calculation was carried out laminar. It documents the stall of flow near at 40 degrees (see also Fig. 2).

An example of simulation results is given by the following Figure 4.

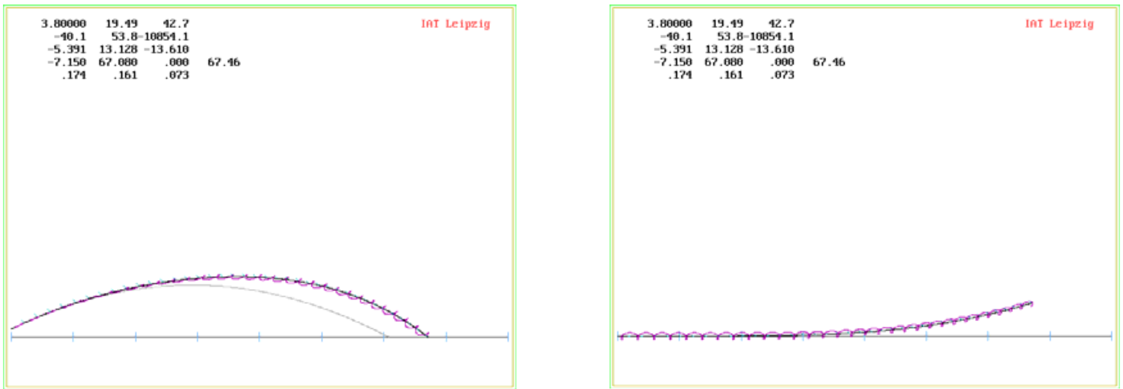

Figure 4 - Simulation without any wind. Left picture: side view of simulated flight curve. Parabola is drawn below. Discus first lies approximately horizontal in the air and spins more and more in a vertical position. Right picture: view from above. It's seen that the discus drifts to the left. The helix line represents the movement of a discus point outside margin.

CONCLUSION: The computer simulation shows, that the combined model of EULER´s equation and flight of centre of mass, including drag and lift, adequately reproduces the obtained behaviour of discus flight in practice. Wind simulation shows that for clockwise turning throwers wind from the right side is optimal to reach best results (it hinders gyration in vertical position). Here one achieves greater distances. Tailwind always decreases lift and reduces distances. Since the discus is less likely to spin out of its previous rotational plane the bigger its moment of inertia about symmetrical axis is, the highest density of the discus should be on its circumference. Competition rules and regulations do not provide any restrictions in this case.

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